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By Stein Atle Lie, PhD, MSc, Nicole Pratt, BSc, Philip Ryan, MBBS, BSc, FAFPHM, Lars B. Engesæter, PhD, MD, Leif I. Havelin, PhD, MD, Ove Furnes, PhD, MD, and Stephen Graves, MBBS, FRACS, DPhil

Investigation performed at The Norwegian Arthroplasty Register, Department of Orthopaedic Surgery, Haukeland University Hospital, Bergen, Norway

Background: There is increased early postoperative mortality after elective joint replacement surgery. However, the magnitude and duration of the increased mortality are uncertain.

Methods: Data on total knee and total hip replacement from the comprehensive national registries in Australia and Norway were assessed. Only patients between fifty and eighty years of age with osteoarthritis were included. Overall, the study included 81,856 patients with a total knee replacement and 106,254 patients with a total hip replacement. Smoothed intensity curves were calculated to show the change in mortality for the early postoperative period, whereas the effects of risk factors were studied with use of the nonparametric additive Aalen model.

Results: We found that early postoperative mortality was increased for the first twenty-six postoperative days (95% confidence interval, twenty-two to forty-one days). The excess mortality, compared with a baseline mortality (calculated as the average mortality from Day 100 to Day 200), for these twenty-six days was estimated to be 0.12% (95% confidence interval, 0.11% to 0.14%). The most important risk factors for excessive early postoperative mortality were male sex and high age (more than seventy years of age).

Conclusions: There is an increased, but low, early postoperative mortality following lower extremity joint replacement surgery. The excess mortality persists, but steadily decreases, for approximately the first twenty-six postoperative days.

Level of Evidence: Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

Total hip and total knee replacements of degenerated joints are highly successful and cost-effective procedures[1]. Nevertheless, the surgical operation itself poses a risk and may even result in death of the patient[2-4].

The crucial magnitude of early postoperative mortality is rarely reported and varies greatly because of differences in patient characteristics[4]. In addition, sample sizes are often too small to produce accurate figures on mortality, and the baseline mortality of the patients at risk is rarely considered.

Previous studies have shown that patients managed with total hip replacement have a higher long-term survival than the general population[5,6], which indicates a selection of healthy patients for hip replacement surgery. Using data from Norway, we also previously showed that patients managed with total hip replacement had an excess early postoperative mortality as compared with a baseline mortality (calculated as the average mortality between Day 100 and Day 200)[7].

To obtain accurate information on the magnitude and duration of the excess early postoperative mortality after hip and knee replacement, a substantial number of patient records is required. We therefore used information from two validated and large national databases on joint replacement patients from Australia and Norway[8-10].

The primary purposes of the present study were to quantify the magnitude and duration of increased mortality following total hip replacement and total knee replacement and to determine if there were differences in the magnitude and duration of this mortality. We wished to obtain information that might be valuable in the decision-making process related to adverse events after lower extremity total joint replacement.

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TABLE I Number of Operations, Age, and Female Sex

	Number of Operations	Age* *(yr)*	Percentage of Patients Who Were Female
Australia			
Total knee replacement	68,708	68.5 ± 7.5	56.1%
Total hip replacement	48,636	67.8 ± 7.8	52.5%
Total	117,344	68.2 ± 7.6	54.6%
Norway			
Total knee replacement	13,148	70.1 ± 6.9	71.3%
Total hip replacement	57,618	69.5 ± 6.9	68.6%
Total	70,766	69.6 ± 6.9	69.1%
Overall total	188,110	68.7 ± 7.4	60.1%

*The values are given as the age and the standard deviation.

Materials and Methods

The present study is based on data from the National Joint Replacement Registry of the Australian Orthopaedic Association and the Norwegian Arthroplasty Register. Both registries provide individual records on all patients and receive records on approximately 95% of all operations performed[9-12].

The Australian registry began collection of data on both hip and knee replacements in 1999, and full national data became available in 2002. The registry collects data on both total joint and partial (hemi) joint replacements. The available Australian data in the time span from 1999 through 2003 were included in the present study. The Norwegian registry began

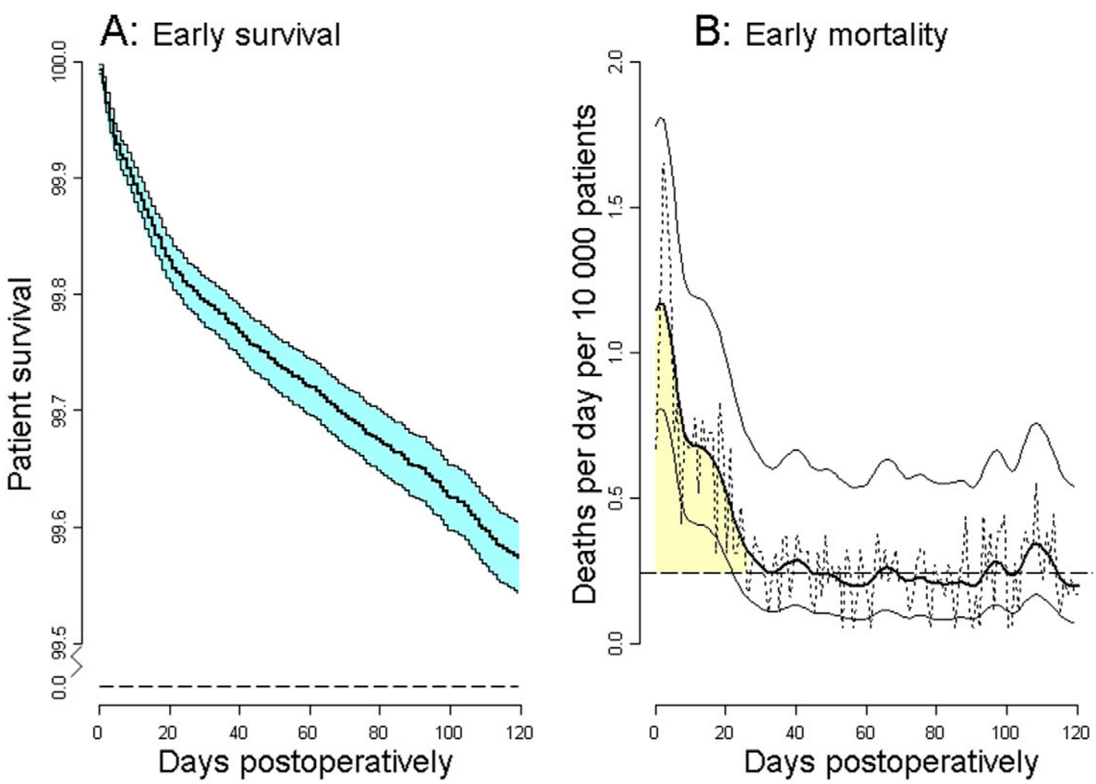

Fig. 1

Graphs illustrating early survival and mortality following total hip and knee replacement surgery. *A:* Total early postoperative patient survival, with 95% confidence interval, after total hip and total knee replacement surgery. *B:* Observed daily mortality (thin dashed line) and smoothed daily mortality (bold solid line), with 95% confidence intervals (thin solid lines) and baseline mortality (horizontal bold dashed line). Excess mortality is the area between the baseline mortality and the smoothed daily mortality.

TABLE II Observed Deaths, Mortality, Baseline Mortality, and Excess Mortality in Ten-Day Categories

Postoperative Days	Deaths	Observed Mortality* *(%)*	Baseline Mortality *(%)*	Excess Mortality* *(%)*
0 to 10	199	0.096 (0.082 to 0.110)	0.024	0.072 (0.058 to 0.086)
11 to 20	122	0.067 (0.049 to 0.085)	0.024	0.042 (0.025 to 0.060)
21 to 30	68	0.035 (0.016 to 0.055)	0.024	0.011 (–0.0087 to 0.031)
First 30 days	389	0.200 (0.180 to 0.220)	0.073	0.130 (0.110 to 0.150)

*The 95% confidence interval is given in parentheses.

registration of total hip arthroplasties in 1987, and all other joint replacements have been registered since 1994. Only total joint replacements (total hip replacements and total knee replacements) were included in the present study. The Norwegian total hip replacement data from 1987 through 2005 and total knee replacement data from 1994 through 2005 were included in the present study.

For the Australian registry, mortality information was obtained by matching patient information obtained at the time of surgery and the death records from the National Death Index using a standard probabilistic matching algorithm (National Death Index, Australian Institute of Health and Welfare). Patient records with no matching death records were excluded from the study after the matching.

For the Norwegian Arthroplasty Register, data from surgery and death files (from Statistics Norway) were matched with use of the unique eleven-digit Norwegian personal identification number. The observation time was considered censored at December 31, 2003, for the Australian data and at December 31, 2005, for the Norwegian data. Individuals who emigrated from Norway (including eighty-one patients managed with total knee replacement and 182 patients managed with total hip replacement) were censored at the date of emigration.

To obtain a homogeneous dataset, we selected only patients with osteoarthritis of the hip or knee who had had a primary total replacement between the ages of fifty and eighty years.

We further categorized the age interval into three bands: fifty to sixty years, sixty-one to seventy years, and seventy-one to eighty years. We also performed subanalyses on patients who had been managed operatively after 1999 to avoid possible confounding effects of the operation year.

Statistical Methods

Survival curves were calculated with use of the Kaplan-Meier method, with log-transformed 95% confidence intervals and a lower limit adjustment for the number of patients at risk.

The early postoperative mortality rate was calculated by means of kernel smoothing (with a normally distributed kernel and seven days' bandwidth) of the observed daily mortality rates. The smoothed mortality curves are presented with point-wise 95% score confidence intervals. The baseline mortality was calculated with use of the average mortality between Day 100 and Day 200. This period was chosen because we expect that the postoperative mortality no longer persists and there should be a minor increase in mortality due to increasing age within this narrow time interval. We calculated the observed mortality, baseline mortality, and excess mortality for ten-day intervals for the first thirty days. The excess mortality was calculated as the difference between the observed and baseline mortality. The day at which the smoothed daily mortality was normalized (reached the baseline) was calculated on the basis of the intersection of the smoothed curve and the baseline mortality with use of a three-day kernel smoothing. The 95% confidence interval for the day on which the mortality was normalized was based on bootstrapping (with use of 1000 samples).

To quantify the time-dependent differences in mortality for patients managed with total hip replacement and total knee replacement according to sex, age, and country, adjusted nonparametric excess hazards were calculated with use of the Aalen additive regression model[13].

Source of Funding

There was no external funding source for the present study. Funding from the Norwegian and Australian governments (and the Australian Orthopaedic Association) was used for expenses related to the operation of the registries (salaries, office space, computers, and so on).

Results

There was a greater proportion of women in the Norwegian registry than in the Australian registry, both for total hip arthroplasty and total knee arthroplasty, and patients were an average of 1.5 years older in the Norwegian registry (Table I) ($p < 0.001$ for all comparisons). The long-term survival of the patients from the two countries and the two joints were almost the same, except for a longer follow-up time for the patients in the Norwegian registry. The data on the two joints for the two countries were therefore merged to calculate the total survival rate. For this total survival rate, the early postoperative phase (up to the 120th postoperative day) is shown in Figure 1, *A*. We observed that the slope of the earliest phase of the curve is steeper at the start, indicating an excess mortality (hazard). The smoothed daily mortality curve showed that the early postoperative mortality was highest immediately after the operation, with slightly more than one death per 10,000 patients per day (Fig. 1, *B*). The mortality decreased thereafter and was normalized (at the lowest level) on the twenty-sixth postoperative day (95% bootstrap confidence interval, twenty-second to forty-first day). The excess mortality for the first twenty-six days was calculated as 0.124% (95% confidence interval, 0.105% to 0.143%) on the basis of Figure 1, *B*. The baseline mortality was calculated as 0.063%, giving an observed mortality of 0.187% (95% confidence interval, 0.168% to 0.206%) for the first twenty-six postoperative days. The accumulated mortalities for the ten-day intervals showed that the excess mortality was highest for the first ten days, low from Day 11 to Day 20, and almost negligible from Day 21 to Day 30 (Table II). This finding was also apparent when the data were stratified according to age category (Table III). When stratified by country, the smoothed daily mortality curves showed that the level and duration of the excess mortality were similar for Australia and Norway.

Figure 2 shows the cumulative excess mortality curves from the additive Aalen model for the included variables. The curves can be read as the approximate number of excess deaths (per 10,000 patients) at the given number of days. For example, compared with women, we saw that, at 100 days, the total number of excess deaths for men per 10,000 patients was ten (Fig. 2, *B*). Thus, we would expect approximately thirty deaths among each 10,000 women (based on the reference mortality, Fig. 2, *A*), whereas we would expect forty deaths among each 10,000 men.

There was significantly increased excess mortality for men as compared with women (Fig. 2, *B*) and for patients with an age of seventy-one to eighty years as compared with those with an age of fifty to sixty years (Fig. 2, *F*). There was no significant difference in the excess mortality for total hip arthroplasty as compared with total knee arthroplasty (Fig. 2, *C*), for Norway as compared with Australia (Fig. 2, *D*), or for patients from sixty-one to seventy years of age compared with those from fifty to sixty years of age (Fig. 2, *E*). From the nonparametric estimates from the Aalen regression, we also found that there was a tendency to an even further increased mortality for the earliest period after the operation for men and for patients from seventy-one to eighty years of age (Fig. 2, *B* and *F*).

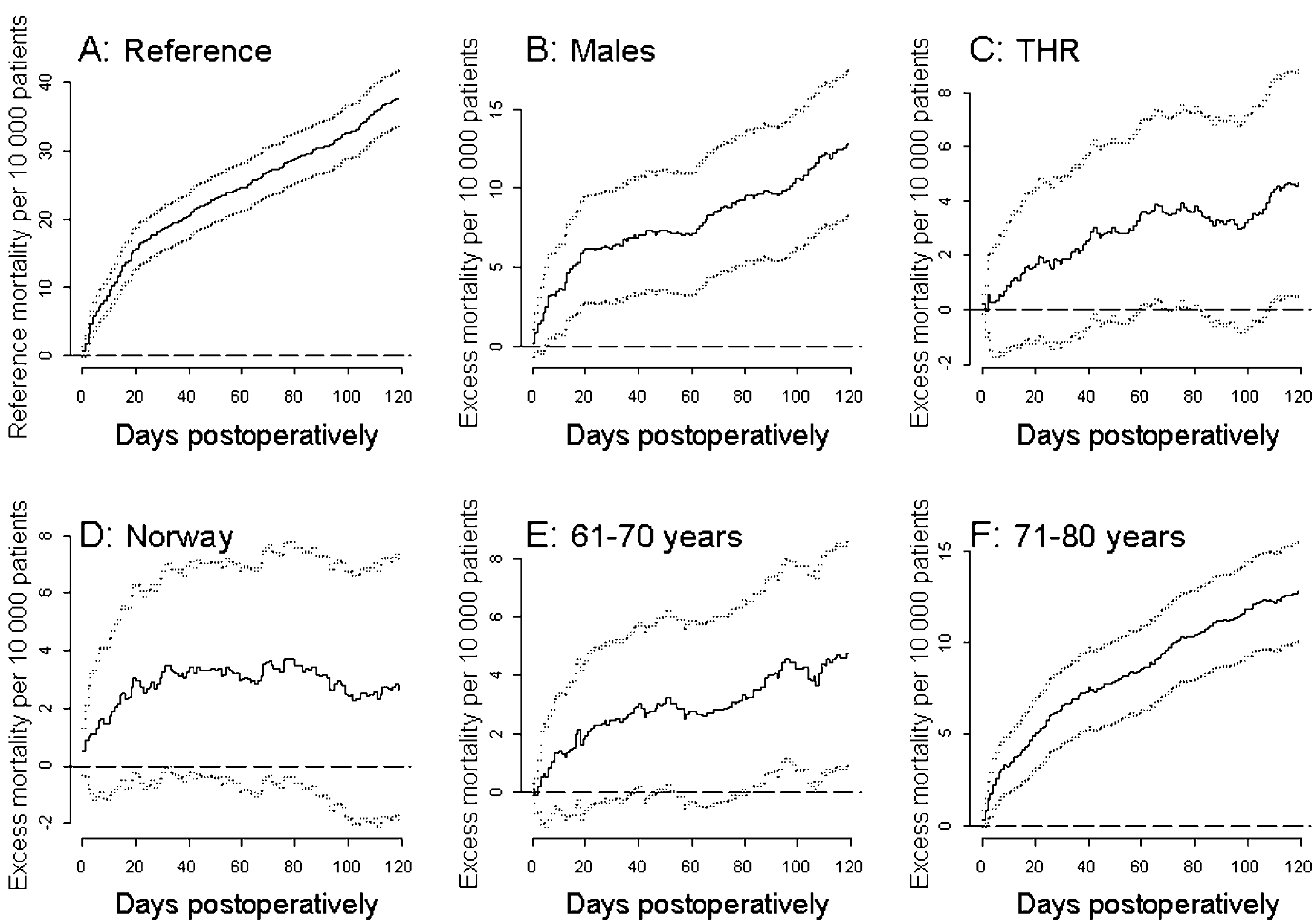

Fig. 2
Graphs illustrating nonparametric (time-dependent) estimates, with 95% confidence intervals, for the cumulative excess hazard from an Aalen model; the horizontal dashed line at 0 represents no effect or difference. *A:* Reference mortality for women, total knee replacement, Australia, and an age of fifty to sixty years. *B:* Excess mortality for men. *C:* Excess mortality for total hip replacement (THR). *D:* Excess mortality for Norway. *E:* Excess mortality for an age of sixty-one to seventy years. *F:* Excess mortality for an age of seventy-one to eighty years.

TABLE III Observed Deaths, Mortality, Baseline Mortality, and Excess Mortality in Ten-Day Categories and Three Age Categories

Age Category	Postoperative Category	Deaths	Observed Mortality* *(%)*	Baseline Mortality *(%)*	Excess Mortality* *(%)*
50 to 60 years					
	0 to 10 days	10	0.036 (0.015 to 0.058)	0.012	0.024 (0.003 to 0.046)
	11 to 20 days	9	0.033 (0.003 to 0.063)	0.012	0.021 (−0.009 to 0.051)
	21 to 30 days	2	0.007 (0.000 to 0.038)	0.012	−0.005 (−0.037 to 0.026)
	First 30 days	21	0.076 (0.045 to 0.110)	0.036	0.040 (0.008 to 0.071)
61 to 70 years					
	0 to 10 days	44	0.060 (0.042 to 0.078)	0.014	0.046 (0.028 to 0.064)
	11 to 20 days	30	0.047 (0.023 to 0.071)	0.014	0.033 (0.009 to 0.057)
	21 to 30 days	12	0.020 (0.000 to 0.046)	0.014	0.005 (−0.02 to 0.032)
	First 30 days	86	0.130 (0.100 to 0.150)	0.042	0.085 (0.059 to 0.110)
71 to 80 years					
	0 to 10 days	145	0.140 (0.120 to 0.160)	0.035	0.110 (0.081 to 0.130)
	11 to 20 days	83	0.091 (0.060 to 0.120)	0.035	0.055 (0.025 to 0.086)
	21 to 30 days	54	0.056 (0.021 to 0.090)	0.035	0.021 (−0.014 to 0.055)
	First 30 days	282	0.290 (0.250 to 0.320)	0.110	0.180 (0.150 to 0.220)

*The 95% confidence interval is given in parentheses.

The subanalyses of data from 1999 did not alter any of the results, except that the slightly, although not significantly, higher mortality for the Norwegian patients in the earliest postoperative phase (Fig. 2, *D*) disappeared.

Discussion

In this observational study involving 188,110 joint replacements, combining data from two national joint replacement registries, we found that there was an increased mortality following joint replacement surgery, which persisted for twenty-six days postoperatively. This excess early postoperative mortality was similar for patients managed with total hip and total knee replacement and for Norway and Australia. However, the overall excess mortality for patients managed with total joint replacement was found to be small (0.12% for the first twenty-six days).

Quantifying the operative risks and excess mortality is important for describing the possible disadvantages of total joint replacements and to target the need for actions to prevent adverse events[14-20]. Replacement of a degenerated hip or knee joint is a very successful procedure for relieving pain and restoring function. However, serious complications such as death can occur[4,15,21]. Still, we do not believe that mortality should be the sole measure after surgery[3].

By combining data from two national joint replacement registries, we were able to study the characteristics of postoperative mortality with use of a large dataset, to calculate mortality (intensity/hazard) curves, and to discover how the mortality changes over time. Using results from studies with preset cutoff points (such as thirty, thirty-five, sixty, or ninety days) to establish how long an increased operative risk persists is common[22-24]. However, the results from such studies merely show that for at least some part of the pre-chosen time point, there may be increased mortality. Therefore, to argue that the increased mortality persisted for as long as sixty or ninety days, on the basis of accumulated figures, may be wrong[25]. Standard statistical tools (such as cross-tables, chi-square tests, logistic regression, or Cox regression) require a preset time point in order to be used. The Aalen regression model, applied in the present study, is not subject to this constraint.

The Australian mortality data were obtained by matching registry data with the National Death Index, a database maintained by the Australian Institute of Health and Welfare. A standardized probabilistic matching routine was used to match patients in the registry with those registered in the National Death Index on the basis of demographic variables such as name, sex, age, or address. We consider it unlikely that early postoperative mortality has any relation to the probability of a match; therefore, bias due to missing data should be negligible.

We have demonstrated that the excess mortality rate is very low (0.12%). Possible mechanisms leading to excess death from the relatively high occurrence of thromboembolic events may involve several known and unknown factors[26,27]. The increase in early postoperative mortality was highest immediately after the operation, and after twenty-one days postoperatively the increase in the early postoperative mortality was negligible. Furthermore, we believe that patient age and sex (which are the most important risk factors) should be taken into account when the individual early postoperative mortality risk is considered. ■

Stein Atle Lie, PhD, MSc
Lars B. Engesæter, PhD, MD
Leif I. Havelin, PhD, MD
Ove Furnes, PhD, MD
Department of Orthopaedic Surgery,
The Norwegian Arthroplasty Register,
Haukeland University Hospital,
N-5021 Bergen, Norway.
E-mail address for S.A. Lie:
Stein.Lie@unifob.uib.no

Nicole Pratt, BSc
Philip Ryan, MBBS, BSc, FAFPHM
Discipline of Public Health, Adelaide Health Technology Assessment,
The University of Adelaide, SA 5005, Australia

Stephen Graves, MBBS, FRACS, DPhil
AOA National Joint Replacement Registry,
Discipline of Public Health, School of Population Health and
Clinical Practice, University of Adelaide, SA 5005, Australia

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